How F-TDMA can improve private land mobile radio

Frequency-and-time-division multiple-access offers a path that allows refarming of existing spectrum below 470MHz to 12.5kHz spacing by on-center channel migration while delivering a 100% increase in efficiency.

By John Yoon and Barbara Baffer

The digital revolution surrounds us.

Compact discs have overtaken audio cassettes and made vinyl records candidates for antique shops. Television manufacturers have invested six years, since 1987, testing alternative architectures.

Ten years ago, the early personal computers were gaining acceptance. Now, multimedia personal computers integrate video, text and sound for learning and research as well as games.

Digital cellular telephone systems operate in Europe, Japan, the United States and Canada.

Land mobile radio is on the verge of exploiting this same digital technology to deliver increased capacity, improved performance and enhanced functionality. A sound foundation is needed before one can build a good quality house. The same is true for fun-

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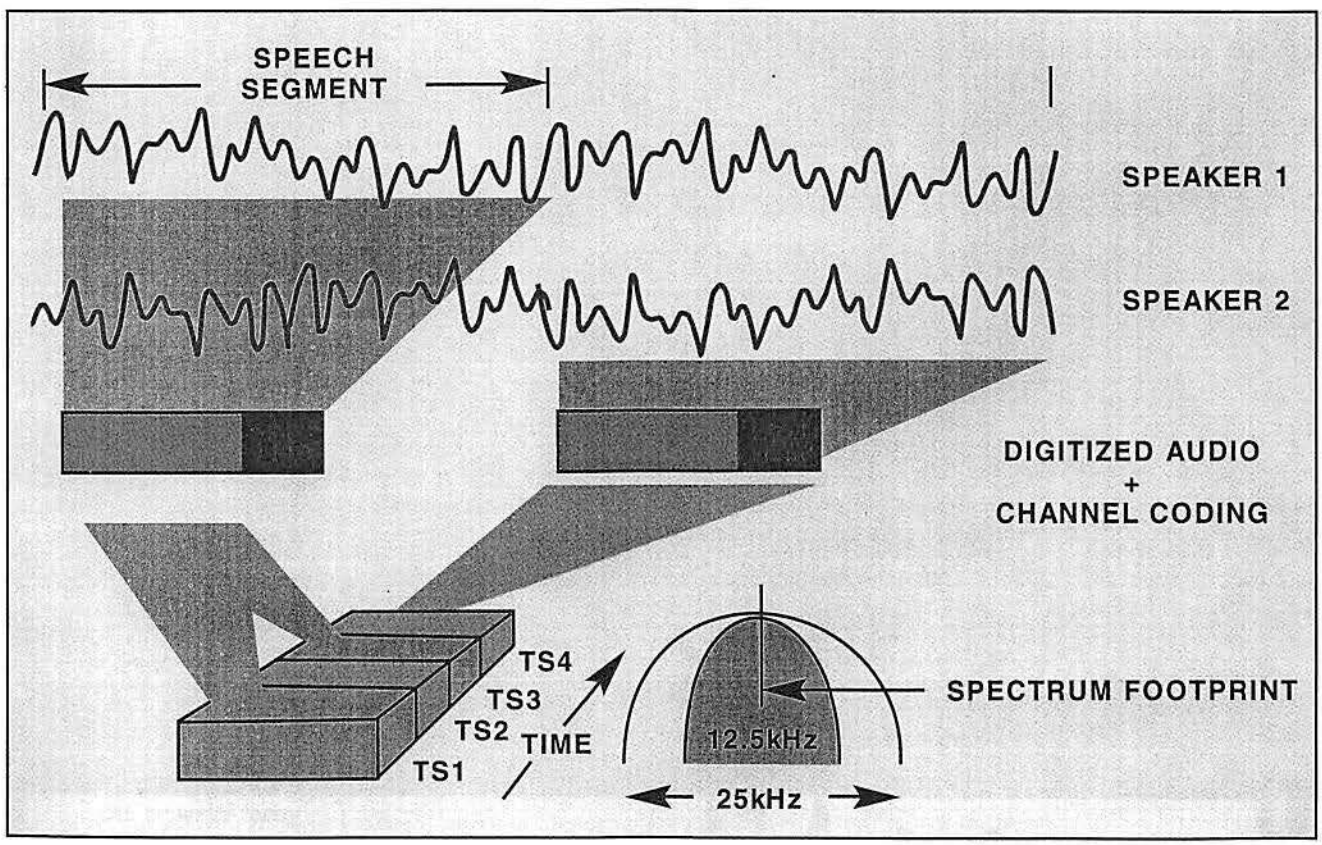

Figure 1. Time-division multiple-access (TDMA) technology allows communications among multiple users by allocating unique time slots to different users. This technique increases capacity by time-multiplexing users on the same RF channel. The shadings represent two distinct user groups. TDMA leaves the channel intact and uses a time reference to keep the data organized within the channel.

damental technology decisions necessary to build an advanced communication system. The architecture is critical to the delivery of promised advantages to land mobile users.

For example, in the mid '80s, the Japanese rushed to adopt a high-definition television (HDTV) protocol. They selected an analog standard because of the speed of product development. They were the first to offer improved video images.

Unfortunately, no other country has adopted that standard, so the Japanese have been unable to capitalize on being first. Other countries, such as the United States, elected to invest in a digital standard that provides not only improved video and sound, but opportunities for television monitors to serve as the interface to interactive services and to advanced home energy control devices, for example.

Meanwhile, the Japanese will have to trade out their broadcasting and receiver equipment again to enjoy these benefits.

This article explains the radio communications benefits promised with digital technology. Time-division multiple-access (TDMA) technology, a spectrum-efficient implementation for digital land mobile radio, is explained. The characteristics of TDMA are contrasted with another approach, frequency-division multiple-access (FDMA). A proposal for TDMA on narrowband, 12.5kHz channels, termed F-TDMA, is described along with its associated advantages.

Digital technology improves voice and data communications performance . . .

Digital advantages

Digital technology offers increased spectrum efficiencies and advanced features.

Specifically, digital technology offers the following:

▶ *Improved performance*—Digital technology improves voice and data communications performance, thanks to sophisticated digital signal processing (DSP) units in mobile and portable equipment.

▶ *Security*—Digitized speech provides inherent protection and a significant level of privacy and security from conventional scanners.

Sophisticated encryption technology can enhance this security for sensitive tactical communications.

▶ *Advanced features*—Digital technology allows the design of a signaling structure with the flexibility to handle several new features, such as:

- □ data-over-voice signaling.
- □ automatic power control of subscriber units.
- □ high-throughput data and dynamic bandwidth applications.
- □ advanced networking and net-

F-TDMA questions and answers

Ericsson-GE responds to some questions about F-TDMA:

MRT: *How is the digital technology developed as F-TDMA for private land mobile radio (PLMR) the same as the digital technology used in cellular mobile telephone systems?*

EGE: By "the same digital technology," we mean the digital technology used in all kinds of products.

With respect to using digital cellular telephone technology for PLMR, advancements in very large scale integrated circuit (VLSIC) technology have provided an avenue for digital signal processors (DSPs) to be developed. DSPs can be programmed to modify or add functions within a system without redesigning a custom IC. In this sense, digital technology can provide PLMR communications with new and powerful capabilities.

The way we use the term *F-TDMA*, the *F* defines a channel bandwidth of 12.5kHz vs. the current 25kHz bandwidth. The key in this design lies in adapting the digital cellular TDMA for PLMR use.

Fortunately, the use of digital components allows most of the changes to be accomplished via software; therefore, it makes sense to say that F-TDMA is exploiting the same technology as digital cellular. This does not mean that F-TDMA has the same system architecture as digital cellular, though. Technology should not be confused with system architecture.

Although a 12.5kHz, 2-slot F-TDMA system is not yet in production, a prototype was demonstrated at the Associated Public-Safety Communications Officers (APCO) national conference in August in New Orleans. A similar 12.5kHz, 2-slot F-TDMA concept is being defined for the Trans-European Trunked Radio (TETRA) RES-6 standard.

MRT: *You have listed a number of advantages that digital technology has to offer PLMR, such as improved performance, security, advanced features and spectrum efficiency. Are these advantages specific to F-TDMA, or can they be delivered by other digital architectures?*

EGE: Digital technology advances most, if not all, radio architectures.

MRT: *Will scanner manufacturers eventually make receivers that can be used to listen to digital communications? If so, how can digital PLMR users protect their communications from competitors and criminals?*

EGE: It is fairly easy to monitor analog FM communications with a scanner. Digital communications cannot be monitored with the same type of scanner.

Digital scanners, if they ever become available, are likely to carry much higher prices because of the more complex circuitry required compared to analog scanners and because of the required economies of scale.

First, casual listeners and scanner hobbyists who make no use of information in conversations they overhear pose no threat.

Second, the average competitor or criminal who eavesdrops only when it is easy and inexpensive, as with an analog scanner, will not be able to listen to digital communications.

Third, if digital scanners become available, digital radio communications technology offers a low-cost software feature for a low level of privacy and security sufficient to prevent monitoring by stock scanners.

Fourth, sensitive business communications that might be the target of industrial espionage and tactical public safety communications that might be the target of sophisticated criminals can be protected with digital encryption standard (DES) encryption.

DES encryption requires such enormous resources and so much time to decode without first knowing the key that the information it protects usually is without value by the time it is decoded.

MRT: *One of the advantages of digital communications you describe is dynamic bandwidth. Does that mean that the bandwidth changes from time to time?*

EGE: Yes, although the bandwidth would not change during a single call.

Dynamic bandwidth might be referred to as *bandwidth on demand.* In an F-TDMA system, the bandwidth never would be greater than what current regulations specify.

Here are two examples of how dynamic bandwidth applies to an F-TDMA system:

(1) An F-TDMA system with dynamic bandwidth equipment offers a migration path from the current "maximum" bandwidth (25kHz) to a "one-half maximum" bandwidth (12.5kHz).

Imagine a single base station that can talk to old (maximum bandwidth) and new (one-half maximum bandwidth) radios. With such a base station, existing radio units do not have to be replaced simultaneously with new units.

(2) Using F-TDMA on a 25kHz channel allows four users to conduct separate communications simultaneously. This type of system configuration is permitted under current FCC rules.

MRT: *Doesn't the promise of digital technology transfer lie in its ability to deliver a high information transfer rate without increasing bandwidth?*

EGE: This is correct; nevertheless, some data applications such as transmitting fingerprint images require a wider bandwidth.

F-TDMA can satisfy requirements for wider bandwidths by providing the flexibility to combine bandwidths of multiple time slots. As technology evolves, the amount of bandwidth required will decrease. Digital technology will promote this bandwidth reduction further, along with the ability to deliver a higher information transfer rate.

Despite the current need for wider bandwidths for specific applications, digital technology not only provides higher information throughputs, but also uses vocoder algorithms to compress voice (which is spectrally inefficient) into a smaller bandwidth.

MRT: *Why aren't high channel data rates possible, such as 16kb/s in a 12.5kHz channel? Why can't a 12.5kHz FDMA channel also operate at a 16kb/s data rate?*

EGE: Data rates are a function of modulation techniques and occupied bandwidth (mask of signal).

The 16kb/s data rate fits within the current FCC Part 88 mask using a 4-phase modulation scheme. A 4-phase modulation scheme ($\pi/4$ DQPSK) is used because this demodulation technique can be implemented easily using today's DSP technology.

More complex modulation schemes, such as 8 QAM and 16 QAM, typically require linear amplifiers to maintain energy within the mask and signal characteristics. Linear amplifier technology is advancing at a rate that should allow these more complex modulation schemes to be applied to digital PLMR in two years or so. Where 4-phase modulation can achieve a 16kb/s data rate, 16 QAM (phase) modulation can increase the rate to approximately 32kb/s.

Another way to improve channel capacity without increasing bits/sec/Hz is by further compressing voice signals into a vocoder. Current vocoder technology compresses voice approximately 4kb/s, but it requires approximately 3kb/s of error correction.

Although this represents significant progress from where technology was a few years ago, improvements in vocoder technology are forthcoming. Higher data rates are possible, but modulation scheme selection is limited by linear amplifier technology and demodulation DSP complexity.

MRT: *Isn't the real issue information transfer rates vs. bandwidth with frequency reuse? Information about adjacent channel protection ratios and co-channel reuse or desired-to-undesired signal ratios would be useful.*

EGE: Yes, frequency reuse is a factor in estimating spectral efficiency.

Our F-TDMA approach uses the same frequency reuse plan that exists today. No new frequency coordination plans are required.

F-TDMA produces 100% spectral efficiency improvement over 12.5kHz FDMA systems and a four times improvement over 25kHz analog systems. The unique feature of F-TDMA is its allowance for transparent migration on existing frequencies without performing a new frequency coordination plan.

work-wide features.

▶ *Spectrum efficiency*—Digital technology, when implemented properly, promises increased spectrum efficiency, i.e., the ability for higher numbers of users to share the same spectrum (higher capacity) or the ability to pass higher quantities of data (higher *throughput*) through a radio system. With available technology, capacity gains of 100% within 12.5kHz channels and at least 300%-440% in 25kHz channels are possible. Data rates exceeding 30kb/s in 25kHz channels or 16kb/s in 12.5kHz channels are possible.

Spectrum congestion is a fact of daily life to many land mobile radio users. The FCC has initiated a *Notice of Proposed Rulemaking* in PR Docket No. 92-235 to *refarm* frequencies below 512MHz to make additional capacity available. Although it is not required by the refarming initiative, digital technology provides a way to gain spectrum efficiency while improving service quality and functionality. The alternative of new, *green* spectrum is not available to meet the demand for private land mobile radio services.

Competing technologies

TDMA is a relatively new entrant into mobile communications and is challenging traditional approaches.

TDMA historically has been projected for 25kHz or 30kHz land mobile channels. A number of countries, including the United States, have adopted or plan to implement 12.5kHz channels in some frequency bands. This has led our company to develop TDMA for operation on narrowband, 12.5kHz channels, termed F-TDMA.

For cellular telephones, TDMA systems are available and operating successfully in many of the large North American markets. Several of the largest specialized mobile radio (SMR) system operators have announced that they will install TDMA technology to gain interoperability and to facilitate wide-area roaming.

The authors' company has supported TDMA for private radio since 1989, when the access technology for private radio first came to be publicly debated in the FCC's *Further Notice of Inquiry* in Gen. Docket No. 88-441.

TDMA uses a common channel for communications among multiple users by allocating unique time slots to different users. This technique increases capacity by *time multiplexing* users on the same RF channel.

The shadings in Figure 1 on page 44 represent two distinct user groups. Each group uses the channel resources on a time-shared basis.

In effect, TDMA leaves the channel intact and uses a time reference to keep the data organized within the channel. The users are not aware that they are sharing an RF channel. Cellular telephone, landline telephone, digital microwave and other electronic switches use a similar technique to multiplex conversations.

Frequency-division multiple-access (FDMA) narrows the channels from 25kHz or 30kHz to 12.5kHz. In some cases, adjacent channel interference prevents simply splitting a 25kHz channel into two 12.5kHz channels.

"Multiple access" is a misnomer in the case of FDMA. In fact, unless the user is licensed to adjacent channels, only one user can occupy the channel at a time.

Incorporating the advantages of narrowband channels with the capacity and flexibility of TDMA, F-TDMA provides two-slot TDMA on 12.5kHz channels, as shown in Figure 2 to the left. Capacity is absolutely doubled on each narrowband channel.

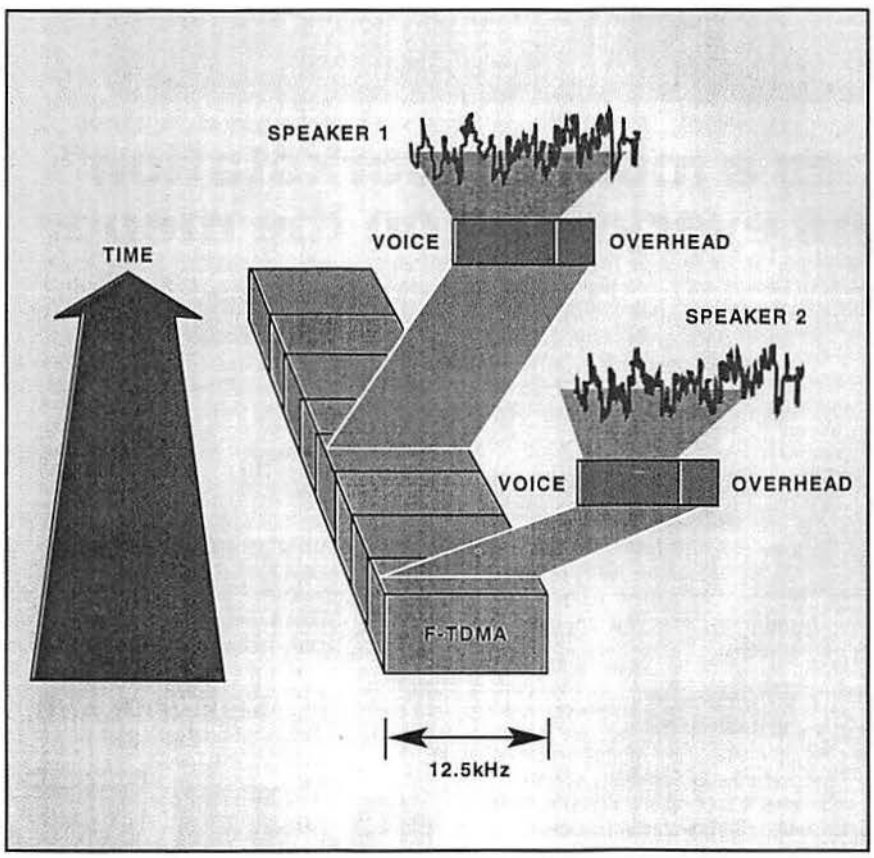

Figure 2. Incorporating the advantages of narrowband channels with the capacity and flexibility of TDMA, F-TDMA provides two-slot TDMA on 12.5kHz channels. Capacity is doubled on each narrowband channel.

Digital modulation

In digital technologies, information is transferred through the air using electromagnetic energy, and the properties of these waves are determined by a modulation scheme.

Modulation techniques often determine the gross bits per hertz. One way digital technologies increase spectrum efficiency is through the modulation scheme. A linear modulation scheme, *differential quadrature phase-shift keying* (DQPSK) is a good match for some

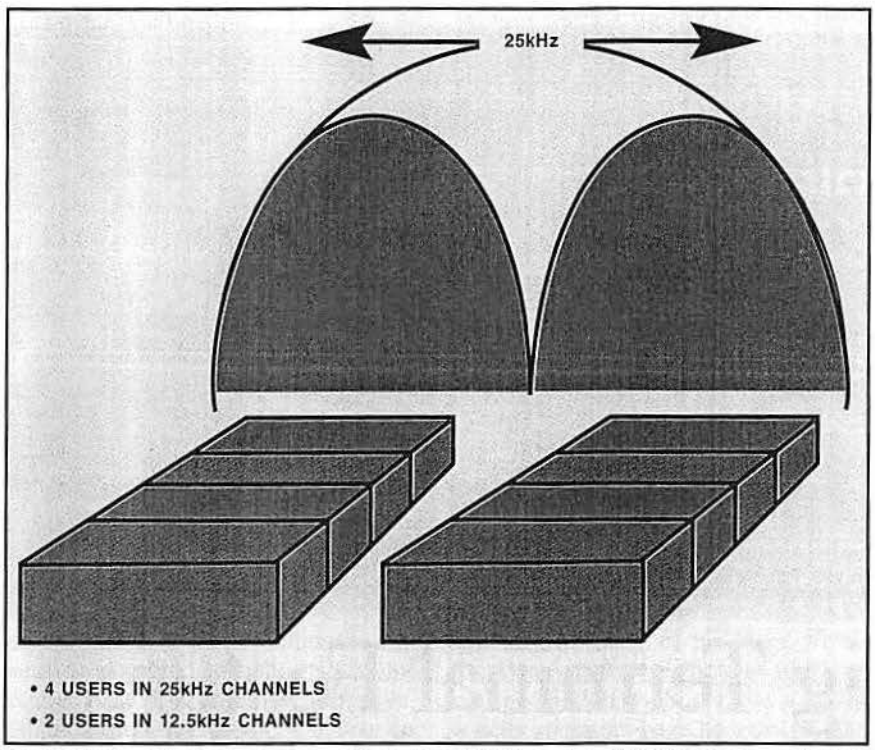

Figure 3. The refarmed spectrum allows two TDMA carriers 12.5kHz apart on a 25kHz channel. This method allows four users on the equivalent of one current channel.

TDMA applications.

DQPSK-modulated F-TDMA can be used in the downlink and can accommodate 16kb/s in a 12.5kHz channel. DQPSK modulation is selected for the downlink communications path to allow simulcast to be implemented. DQPSK represents digital data by shifting the relative phase of the carrier to represent digital symbols. The uplink path, mobile-to-base, will be supported by *continuous phase partial response modulation* (CPM) that eliminates the need for linear or quasi-linear amplifiers in hand-held equipment.

Vocoders

Voice coders (vocoders) are used in digital systems to convert analog speech into digital signals for transmission.

At the receiving end, the vocoder translates the digital signal back into analog speech.

To increase the information transmission efficiency for digital private

land mobile radio systems, the vocoder's data rate must be decreased. This rate reduction is accomplished within the vocoder, which removes redundancy in the speech signal waveform.

Therefore, the *improved multiband excitation* (IMBE) vocoder, based on its superior test performance and availability, is selected for use in F-TDMA equipment. The IMBE vocoder's data rate allows two users to communicate simultaneously within the channel capacity of 16kb/s in a 12.5kHz channel.

Linear amplifiers and TDMA

Continuous phase modulation (CPM) is used in the uplink. This method offers a particular benefit in digitally modulating mobiles and portables because non-linear amplifiers still cost less than linear amplifiers. The cost advantage, along with the higher efficiencies of non-linear amplifiers, makes CPM a logical choice for portable F-TDMA radios.

Using DQPSK on the downlink requires a linear or linearized amplifier; still, modulation is used only for base stations where this technology is widely available. DQPSK is a good modulation choice for the downlink because any receiver capable of modulating and demodulating DQPSK is capable of decoding other modulation schemes.

By narrowing the bandwidth and applying F-TDMA technology, multiple spectrum savings are achieved.

Talk around or simplex

Because F-TDMA is compatible with 12.5kHz operation, talk around is also possible.

Any F-TDMA radio can operate in the talk-around mode by operating in an FDMA mode, using QPSK modulation and 12.5kHz digital talk around. QPSK is a 4-phase modulation technique in the same family as CPM. Channel efficiency is not compromised when the radio operates in the talk-around mode.

F-TDMA on existing channels

By narrowing the bandwidth and applying F-TDMA technology, multiple spectrum savings are achieved.

The F-TDMA technology provides the equivalent of 12.5kHz channelization on existing 25kHz allocations (e.g., 806MHz-821MHz or 450MHz-470MHz), a twofold increase in current National Public Safety Planning Advisory Committee (NPSPAC) channel allocations (821MHz-824MHz), and a migration path to the proposed 12.5kHz channels below 512MHz.

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On-center narrowband channels will be used. This method allows existing channels to be upgraded without having to create new narrowband channels.

F-TDMA on refarmed spectrum

The refarmed spectrum allows two TDMA carriers 12.5kHz apart on a 25kHz channel. (See Figure 3 on page 52.) This method allows four users on the equivalent of one current channel.

F-TDMA technology provides the best solution to satisfy the need for increased spectrum efficiency in land mobile radio while offering the flexibility of supporting high data rates. Moving to narrowband channels alone, as proposed by Project 25, is inadequate to meet the demand for increased spectrum. (Project 25, a joint effort of the Associated Public-Safety Communications Officers, the National Association of State Telecommunications Directors and federal agencies, seeks to set digital radio standards for public safety radio communications.)

Although the use of analog technology may continue for some time, in due course digital will supplant analog. It is imperative that sound migration plans be available for the transition from analog to digital systems and for maintaining backward compatibility between existing and upgraded systems.

F-TDMA offers backward and forward compatibility. F-TDMA technology has a migration path to achieve a capacity of four users in 25kHz channels under uniform emissions standards. Furthermore, the F-TDMA architecture is fashioned to accept increases in spectrum efficiency.

F-TDMA will benefit significantly from technological advances in other fields. Microprocessors, software and batteries will be leveraged for private land mobile radio systems. Using such components provides economies of scale that will help to lower the price of TDMA.

F-TDMA data performance

F-TDMA inherently provides 67% higher throughput (16kb/s vs. 9.6kb/s in 12.5kHz channels) than FDMA.

Data applications that require transmissions of fingerprints and retinal scans require wider bandwidths. F-TDMA provides the flexibility to combine bandwidths of multiple time slots and pass data, which requires a wider bandwidth to transmit.

F-TDMA offers a path that allows refarming of existing spectrum below 470MHz to 12.5kHz spacing by on-center channel migration while delivering a 100% increase in efficiency.

Current 800MHz radio users can maintain their existing 25kHz channels and gain a progressive efficiency increase to four users per channel using F-TDMA.

F-TDMA will be developed and implemented with product availability within the next two years.